VEGETATION REFLECTANCE (R) AND FLUORESCENCE (F) FOR *PLANT PHYSIOLOGY*,

Assessment of the Contribution of Chlorophyll **F** to **R**

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NASA's goals and concerns: *1) determination of the capacity of plants to sequester carbon and 2) quantification of carbon and nutrient storage and fluxes, disturbance and recovery processes and ecosystem health.*

•Current remote sensing estimation of vegetation biophysical parameters have serious limitations.

• Information on vegetation physiological condition can be obtained *directly* by **F** and possibly via hyperspectral **R** (≤10 nm resolution).

While it has been assumed that **F** is a very small portion of the apparent vegetation reflectance (Ra), further research is needed to quantify the contribution of **F** to **Ra**, especially in the red and far-red where the **ChlF** emissions are maximal, and to validate the potential of **ChlF** for diagnosis of vegetation physiological condition using as excitation the full solar spectrum.

GOALS

- Compare the ability of **F** and **R** measurements to separate vegetation stress levels.

- Evaluate the relative **R** and **ChlF** fractions contributing to the cumulative vegetation irradiance at 685 and 740 nm, using near solar excitation.

OBJECTIVES

1) Identify the **R** and **F** indices with highest separation capability,
2) Determine if **F** provides additional information not provided by **R**,
3) Evaluate the relationship between **R** and **F** spectra, and
4) Quantify the contribution of **ChlF** to **Ra**.

PART I

Vegetation stress detection via **REFLECTANCE** or **FLUORESCENCE**

MATERIALS and METHODS

- ***Vegetation treatments:***
  - * **Corn** (*Zea Mays* L.)

    Field soil nitrogen (N) treatments (N in % of optimum=100%).

  - * **Soy bean** (*Manokin* var. - O_3 sensitive; *KS4696* var. - CO_2 sensitive)

    Open top chambers treatments

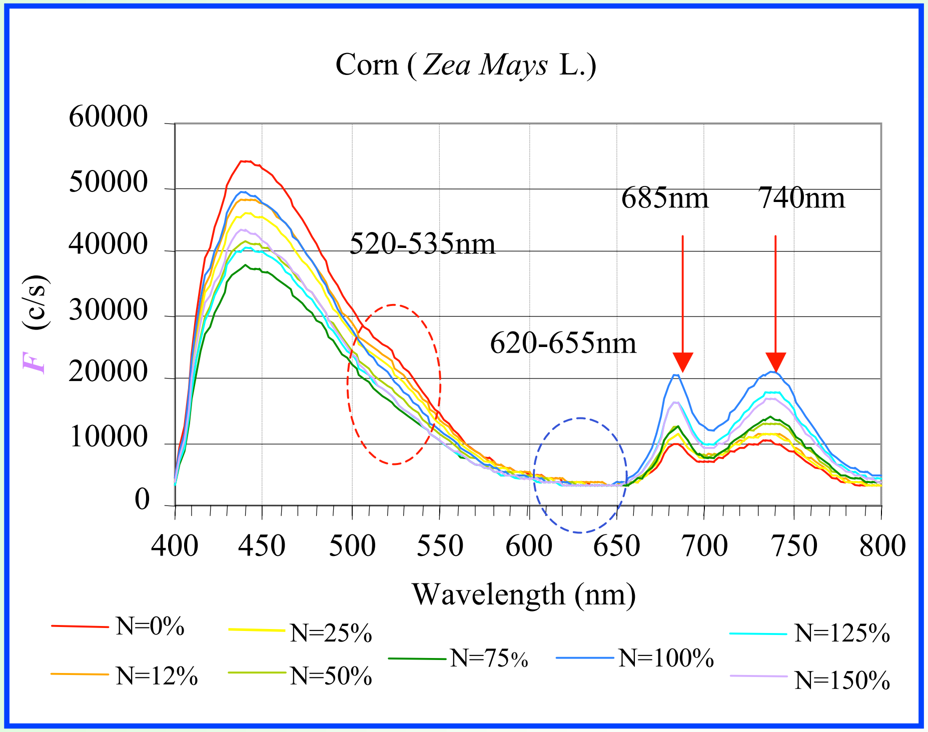
    Elevated above ambient: O_3, CO_2, (O_3+CO_2) and Charcoal filter (CF).

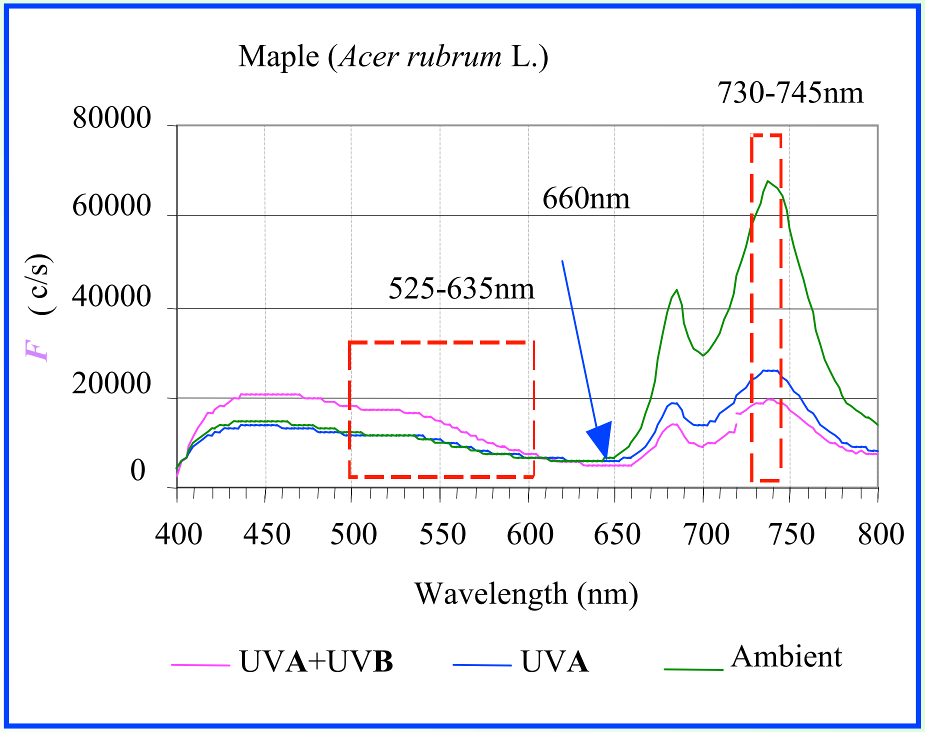
  - * **Maple** (*Acer rubrum* L.)

    Field treatments: 2x ambient UV-A, UV(A+B) and Control (ambient UV).

- ***Measurements***
  - * **Determinations of Foliar Pigments and Analytical Chemistry (C, N, H)**
  - * **Foliar Fluorescence Emissions (F)**
  - * **Foliar Reflectance Spectra (R)**
  - * **Simultaneous acquisition of fluorescence, reflectance and F+R spectra**

RESULTS: ***Changes in F*** *(Ex.=360nm)* ***associated with vegetation stress***





- Differences in corn (C4) ***F*** indicative of increasing soil **N,** occurred around 530 nm and in the 680-760 nm

- Under increased UV radiation significant changes in maple (C3) ***F*** occurred in the same spectral regions as in corn, but the magnitudes differed (blue F vs. Chl F).

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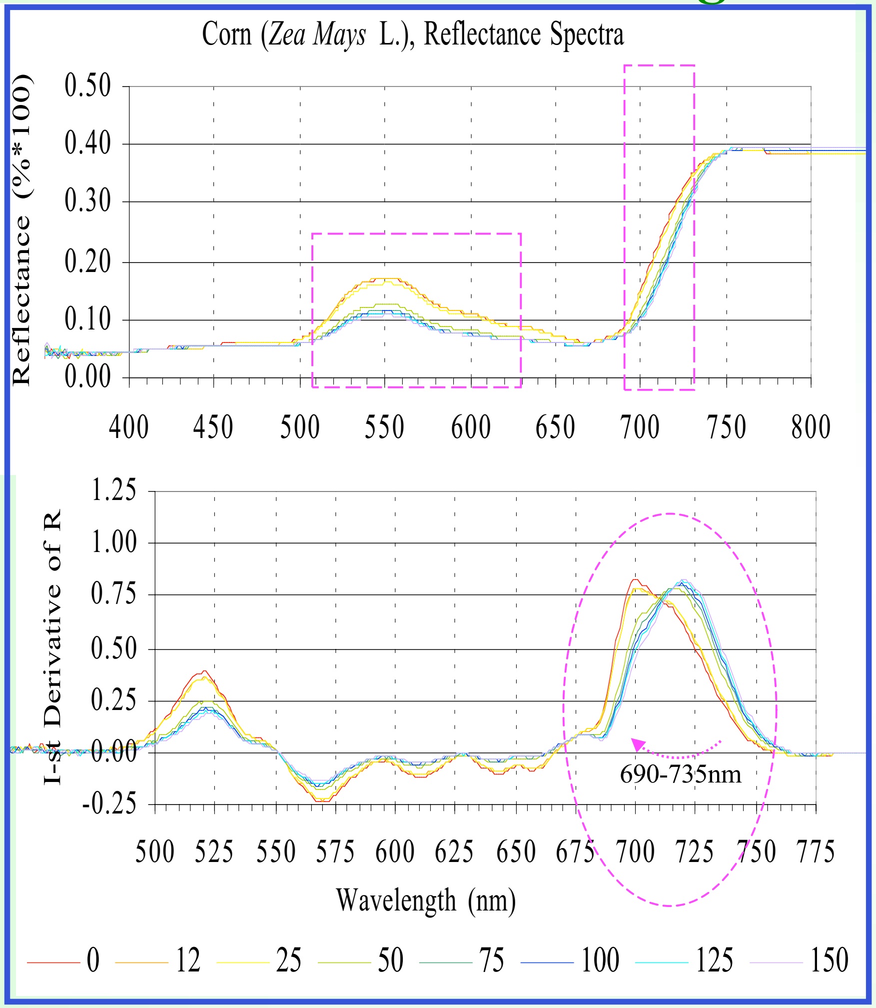
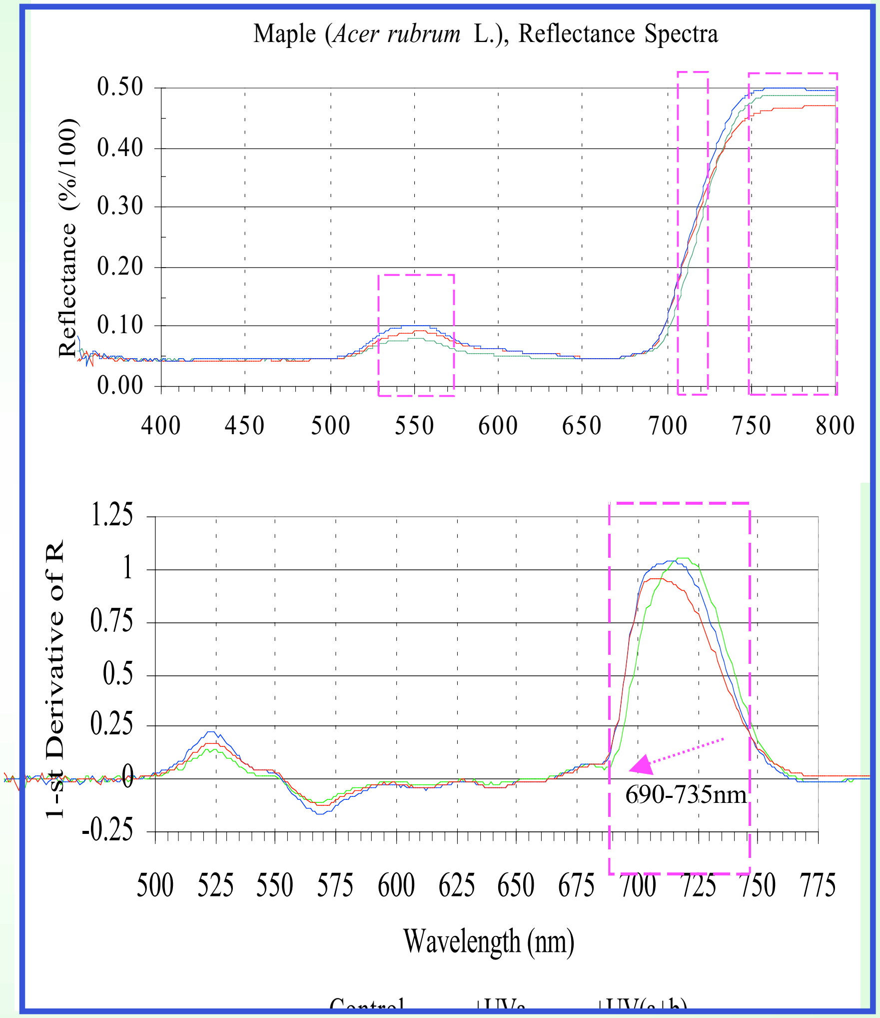
RESULTS: *Changes in Foliar R Spectra associated with vegetation stress*





- Differences in corn, maple and soybean ***R*** indicative of the stress treatments, occurred around 550 nm and in the 690-735 nm.

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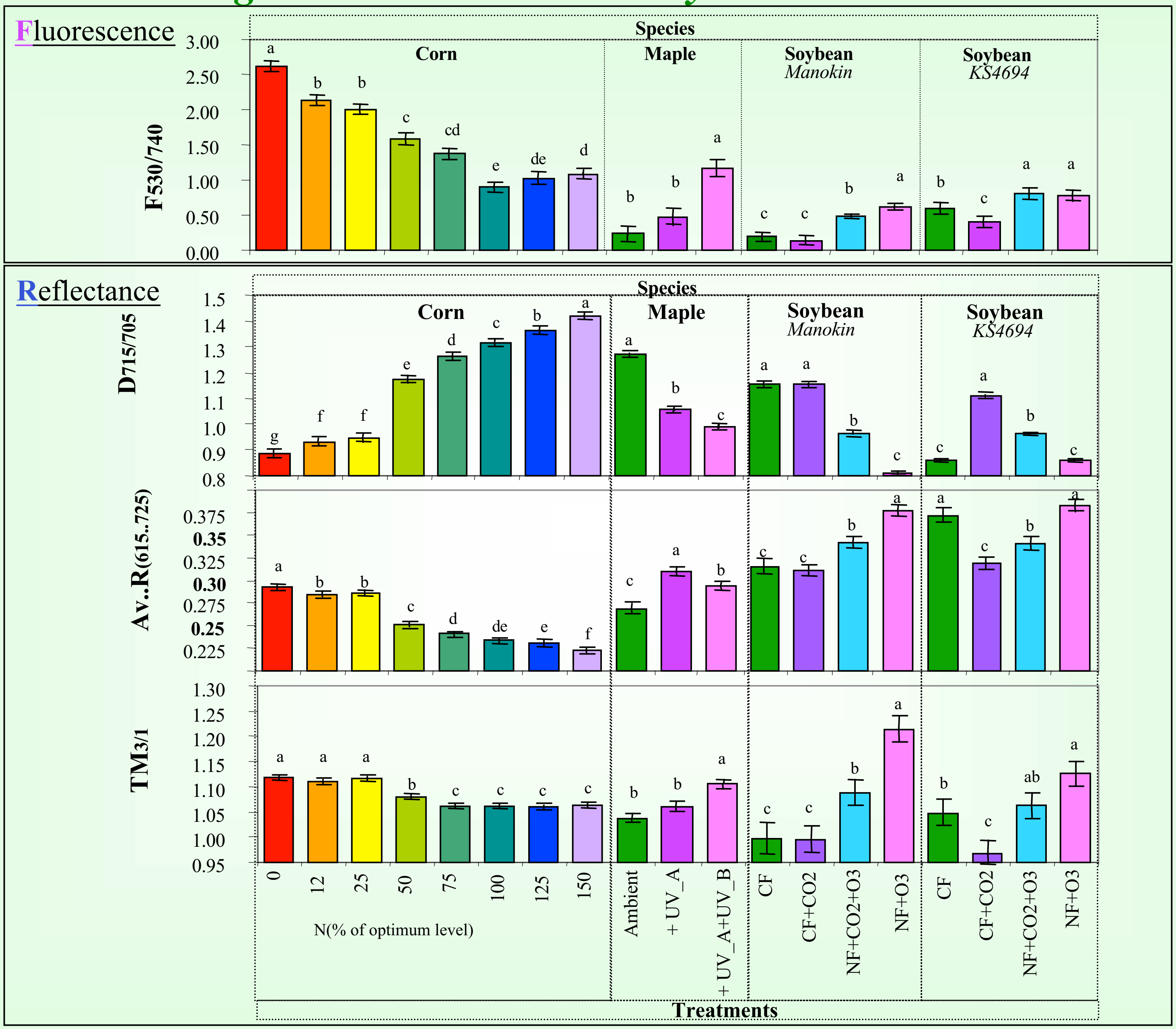
Vegetation stress detection by F and R indices



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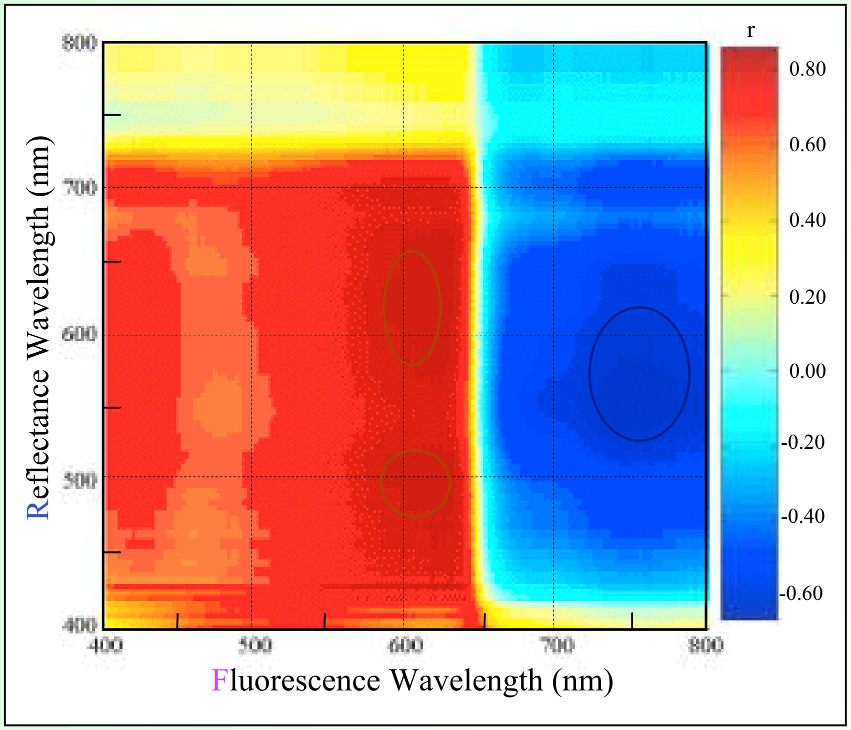
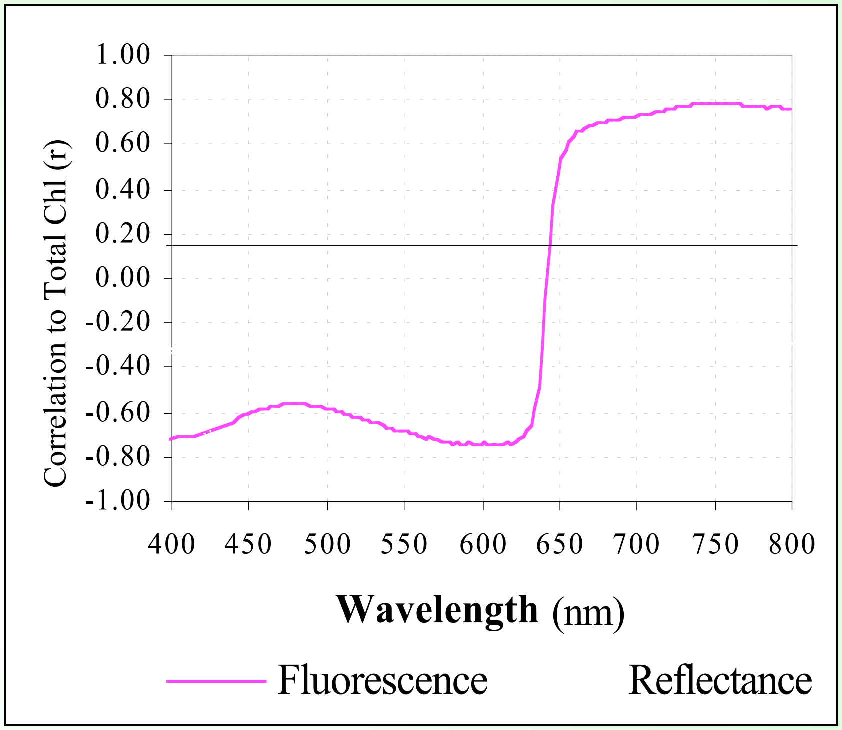
Correlation between foliar F (360 nm excitation) and R spectra, Correlation of F and R to total Chlorophyll





Data from Soybean (*Glycine max.*) *Manokin var.*, ab-axial leaf surface.

•Correlation between F (F, 360nm excitation) and R foliar spectra (r correlation coefficients).

- negative correlation: F450-640 X R450-720nm
- positive correlation: F670-800 X R450-720nm

•Correlation between foliar F (360 nm excitation) and total chlorophyll content.

•Correlation between foliar R and total chlorophyll content.

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SUMMARY

- Hyperspectral **R** indices were optimal, as compared to individual **F** or **R** broadband indices for treatment separation.

- Extreme **F** levels were observed at the optimal level for all treatments and species, therefore the **F** provided the ability to identify the optimal vegetation condition.

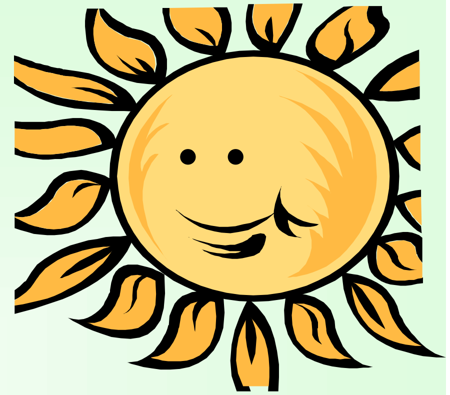
- Spectral **R** data provided a sufficient capability for treatments discrimination and N deficiency detection in corn. The **R** indices were linearly related to the treatments, with a continuous gradient for corn across all N treatments.

- The current methods for assessment of photosynthetic function and carbon sequestration, based on the combined satellite observations and modeling efforts, could be improved by incorporating the physiological information obtained using both hyperspectral **R** and/or **F** emission measurements.

PART II

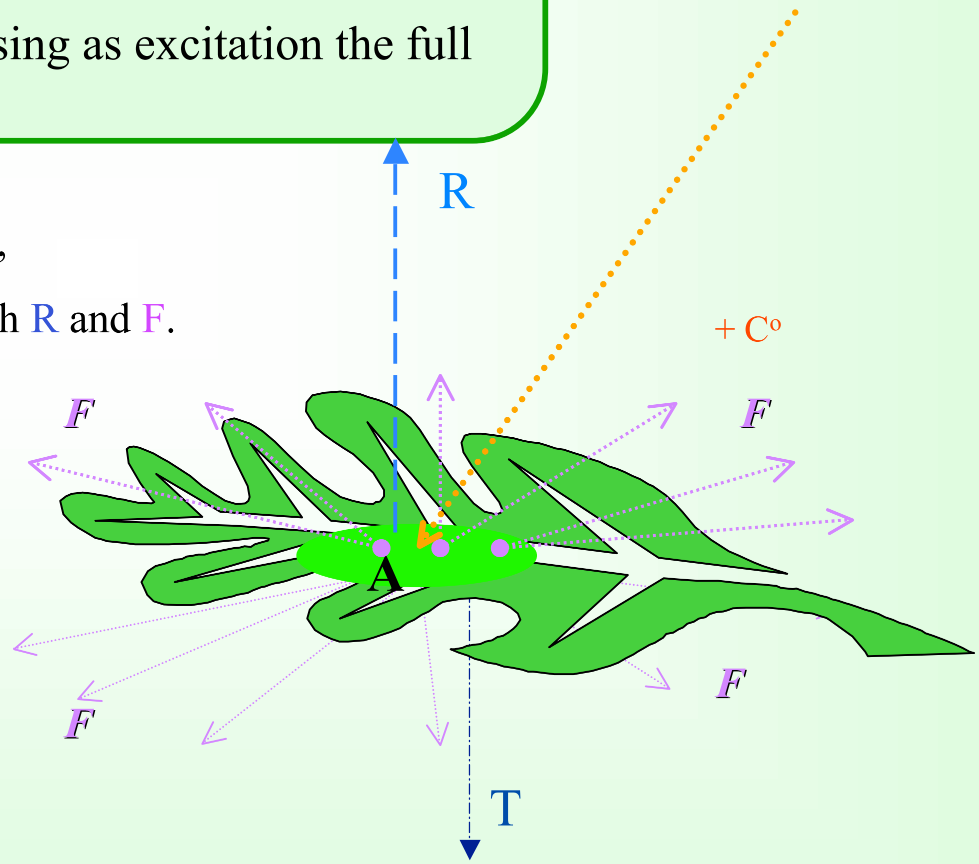
- Determine the relative contribution of Chlorophyll **FLUORESCENCE** to foliar **REFLECTANCE i**n the red/far-red region.

- Validate the potential of **ChlF,** using as excitation the full solar spectrum



The apparent vegetative reflectance (Ra),

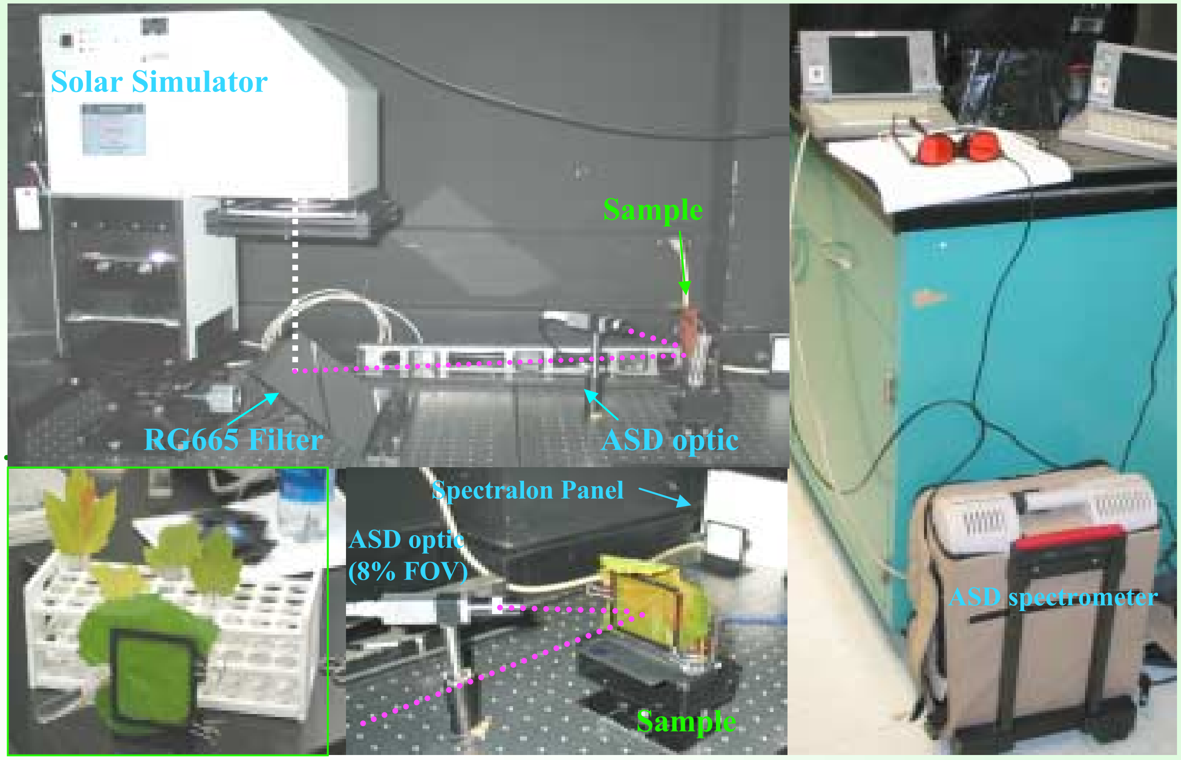
typically includes the contribution of both R and F.

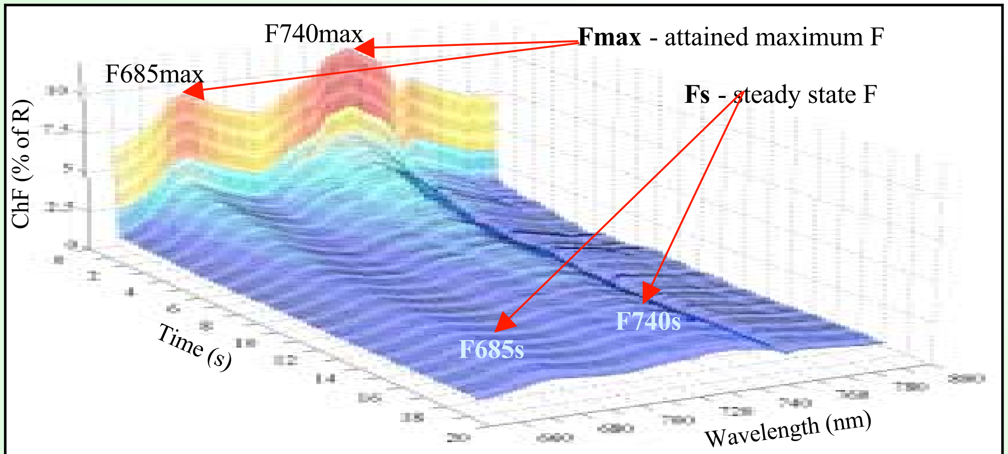


Acquisition of

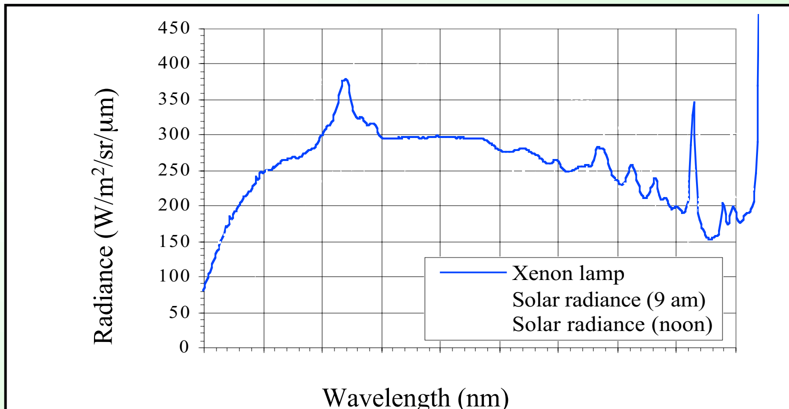
***F** and **R** spectra*

($W/m^2/sr/\mu m$ and % of incoming).

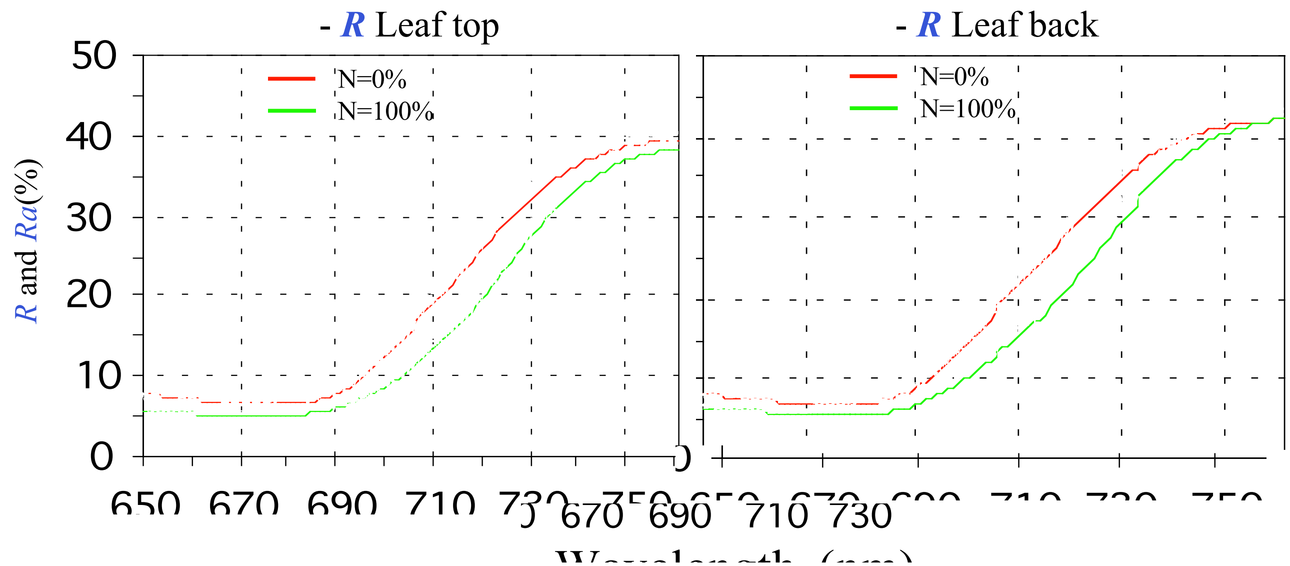




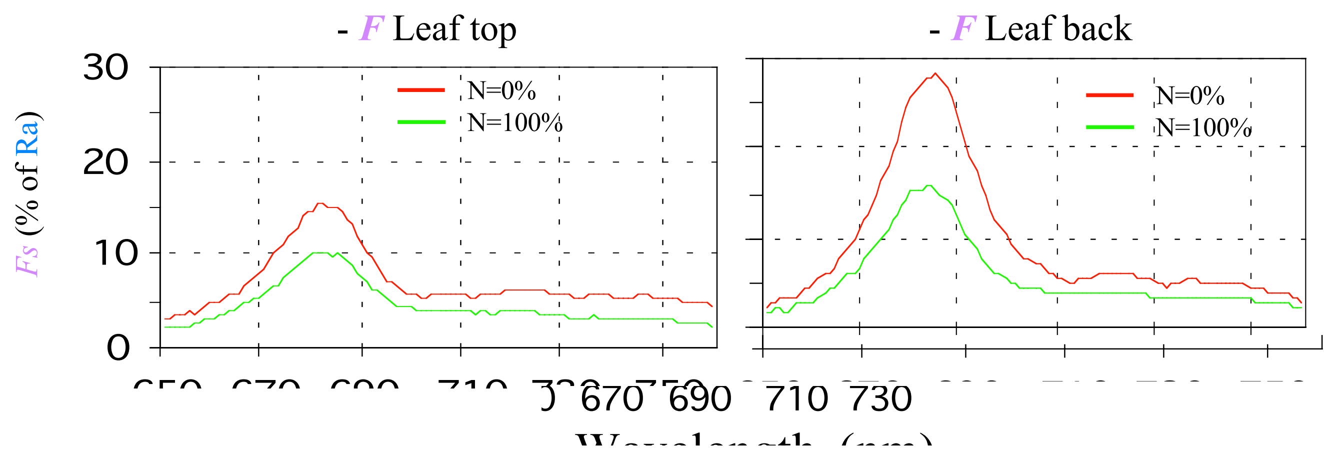
Chlorophyll fluorescence spectra of corn foliage (Zea Mays L).



Solar spectra and radiation output of the xenon arc lamp used as **R** illumination and **F** excitation source.



Reflectance (R) and apparent reflectance (Ra) of corn foliage (ANOVA Means).



Contribution of steady state fluorescence (Fs) to the apparent foliar reflectance (Ra) (ANOVA Means). Fs is expressed as percentages of Ra.

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RESULTS: *Changes in Fluorescence (F) associated with nitrogen treatment**

Fluorescence parameter	Nitrogen treatment level (N in % of optimum, Means and r^2)								
	Leaf adaxial (top) surface					Leaf abaxial (back) surface			
	0	50	100	150	r^2	0	50	100	150
1. Fluorescence amount at 685 and 740 nm expressed as % of the incoming radiation									
F685max (% Incoming)	2.98ns	2.65ns	2.51ns	2.65ns	0.35	3.53a	3.76ab	3.98b	3.48a
F685s (% Incoming)	**1.07a**	**0.79b**	**0.41c**	**0.67b**	**0.74**	0.98ab	1.21ab	1.36b	1.09a
F685slope	-0.076a	-0.06ab	-0.05b	-0.05ba	0.69	**-0.19a**	**-0.12b**	**-0.06c**	**-0.06c**
F740max (%Incoming)	3.48a	4.08bc	3.91b	4.40c	0.61	**4.29a**	**5.15b**	**5.71c**	**4.71b**
F740s (%Incoming)	**1.02a**	**1.04a**	**0.78b**	**1.03a**	**0.62**	1.28a	1.30ab	1.61b	1.29ab
F740slope	-0.11 ns	-0.10 ns	-0.09 ns	-0.10ns	0.46	**-0.24a**	**-0.20b**	**-0.13c**	**-0.12c**
2. Fluorescence amount at 685 and 740 nm expressed as % of radiation reflected of the vegetation (R)									
F685max (% of R)	35.8	30.8	46.7	44.9		46.8	49.3	61.4	52.3
F685s (% of R)	15.2	11.0	10.0	12.8		15.5	16.2	28.3	24.7
F740max (% of R)	9.5	8.8	11.4	12.0		11.0	12.2	14.5	11.8
F740s (% of R)	5.5	4.5	3.1	3.3		3.4	3.7	5.0	5.0
3. Fluorescence amount at 685 and 740 nm (W/m^2/sr/μm)									
F685max (W/m^2/sr/μm)	5.1	4.3	5.5	5.3		7.4	8.1	8.7	7.0
F685s (W/m^2/sr/μm)	2.0	1.4	1.3	1.5		2.4	2.5	3.4	3.2
F740max (W/m^2/sr/μm)	9.6	8.7	10.5	11.6		11.9	13.1	14.7	12.0
F740s (W/m^2/sr/μm)	5.3	4.3	2.9	3.2		3.7	3.9	5.0	4.0

* Means are compared within row per leaf surface, indicating significant differences among treatments with different letters (ANOVA)

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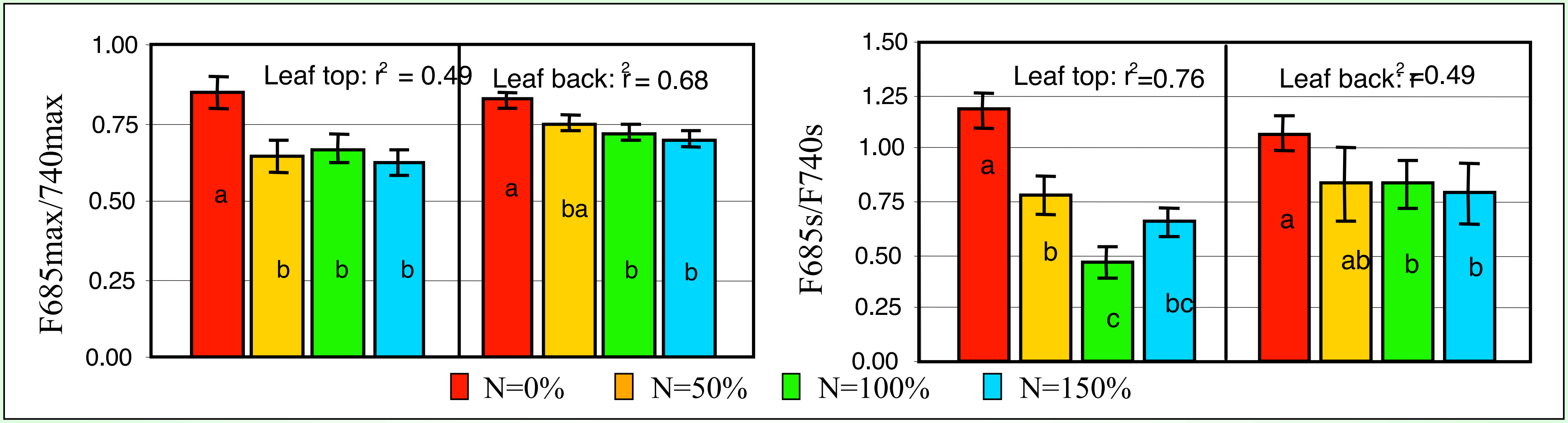
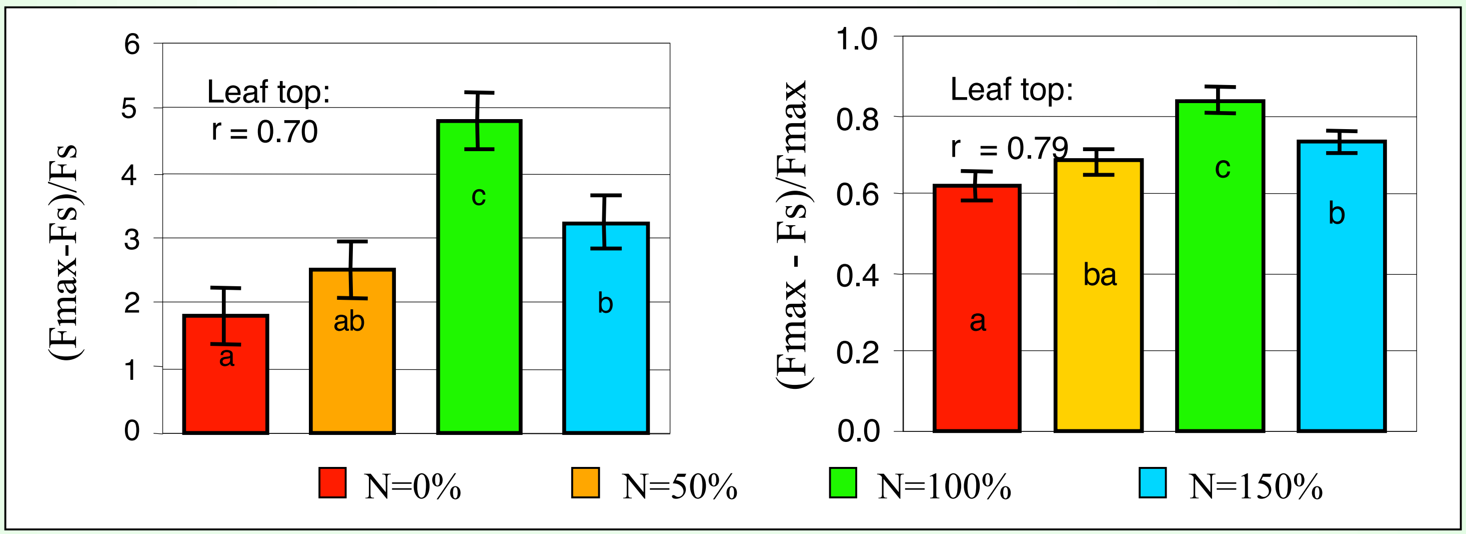


Differences in the corn Fred/Ffar-red ratio associated with nitrogen treatments (ANOVA, Means and Std. Errors).



Differences in the corn foliar F685vs [F685vs=(Fmax-Fs)/Fs] and F685vm [F685vm=(Fmax-Fs)/Fmax)] parameters in association with nitrogen treatment.

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SUMMARY

- This investigation confirms the significant contribution of **ChlF** to the apparent vegetation **R** in the red and far-red regions (at 685nm Fs=10-25%, at 740nm Fs=2-6%).

- The relationship between foliar **F** and **R** was significantly affected by the bio-physiological status of the vegetation. The relative **Fs** fraction at 685 nm increased in concert with the nutrient stress levels, based on leaf adaxial (but not abaxial) measurements.

- Using near solar excitation spectrum, this study confirms the trends associated with vegetation stress in **Fs685/740**, **Fvs** and **Fvm** ratios established with single spectral excitation bands. This finding suggests that the **ChlF** utility for monitoring the physiological status of vegetation, established by the **active** **ChlF** technology is likely applicable under natural solar illumination.

RESEARCH DIRECTIONS

Future research is needed to extend our findings to other vegetation types and species, and to evaluate the association of photosynthetic function and the corresponding vegetation fluorescence emissions and hyperspectral reflectance properties.

ACKNOWLEDGEMENTS

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